A New Approach to Evaluating Fatigue Life of Fillet Weld

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1. Objective of Research

Fillet weld is one of the most frequently used welded joints in bridge structures. Fatigue strength of fillet weld has been specified for some typical details in fatigue design recommendations. However, there are many complicated details, which cannot be, or are inappropriate to be analyzed by the typical classified details. In some cases, hot spot stress (HSS) method may be applied to evaluate those unclassified complicated details. Typically, HSS methods extrapolate the geometric stress at weld toe with calculated or measured surface stresses at 2 or 3 locations near the toe. Up to now several HSS methods have been proposed. However, each has some limitations in application and universal method has yet to be found. With these in consideration, this research aims at providing a practical approach to evaluating fatigue life of common as well as complicated details containing fillet weld.

2. Fatigue Life Estimation Based on Global Stress Concentration

Fatigue crack of fillet weld usually occurs at weld toe region where exits a high stress concentration, and the extent of stress concentration determines the magnitude of fatigue life to a large extent. The stress concentration at toe comes from the geometry changes induced by both the weld profile and attachment, if the weld is used to joint it to the structure. The whole stress concentration will be the product of both parts, as shown by Eq. (1).

$$K_t = K_{t,global} \times K_{t,local} \qquad (1)$$

Where, $K_{t,global}$ and $K_{t,local}$ indicate stress concentration from weld profile and attachment respectively. It is difficult to control the profile of the weld bead, and the shape and size of the bead vary from one location to the other even in the same joint. This variation can partially explain the scatter of the fatigue test data. In this research, a non-load-carrying cruciform joint shown in Fig.1 is taken as a reference detail to express the local stress concentration at toe region. There are two reasons for taking this detail as a reference. One is that many fatigue tests have been carried out on non-load-carrying cruciform joints and adequate data are available. The other is that the part of stress concentration due to the attachment is relatively small, and its $K_{t,global}$ can be reasonably taken as unity. The global stress concentration of any other detail with fillet weld can be obtained by comparing its stress distribution with that of the reference detail. If test data of these details are plotted in global stress range (nominal stress range multiplied by $K_{t,global}$) rather than in nominal stress range, the scatter of test data will only reveal the influence of weld profile, and test data of all fillet welded details should be located within the same region as those of the reference detail. In this sense, it might be said that the reference detail serves as a unified fatigue strength representation for all fillet welded details.

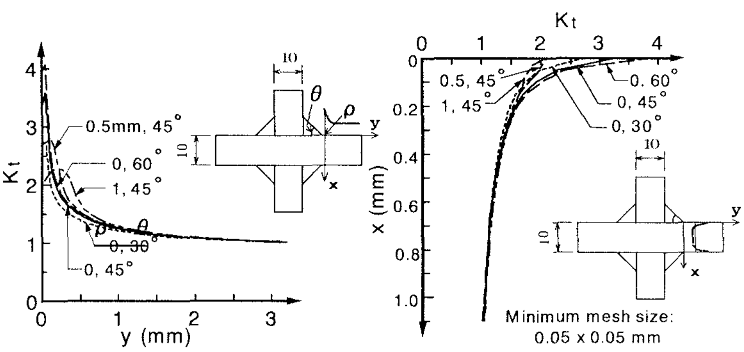

Fig.1 Reference Detail

It is shown by FEM analysis that the local perimeters of weld profile, weld toe radius, ρ, and weld toe angle, θ, have a remarkable influence on the stress concentration at weld toe (Fig.1), but the affecting region is limited. For instance, beyond 1mm from toe in the direction of crack propagation (x-direction), the stress distribution does not change significantly with ρ or θ. It follows that the global stress at 1mm from toe along crack propagation path might be chosen as a representing value for weld toe region in order to get a less varied number.

Higher (in a sense, more exact) stress concentration values might be obtained with finer mesh when analyzing with

FEM. Therefore, the weld toe region of the structural element to be investigated should be analyzed with fine mesh to get a relative precise K_t distribution, and the reference detail should also be analyzed with the comparable mesh to get its $K_{t,local}$. Following Eq. (1), the $K_{t,global}$ distribution at weld toe region can be obtained by taking the ratio of K_t to $K_{t,local}$. Finally, the representing value of $K_{t,global}$ for fatigue life evaluation can be taken at 1mm from toe in the direction of crack propagation. The $K_{t,global}$ distributions at weld toe region calculated for in-plane-gusset test specimens following the abovementioned procedures are shown in Fig.2. The minimum mesh size at weld toe region is 0.2 x 0.2mm. The three curves with solid rectangular, triangular, and circular symbols indicating locations of nodes show the results of specimens with gusset length of 50, 100, and 200mm, respectively.

On the other hand, in engineering practice, the time and cost associated with calculation with extreme fine meshes could not be afforded, especially in the case of 3D FEM analysis. Mesh effects were investigated with in-plane gusset specimens, and the results were shown in Fig.2 with blank symbols. Three mesh sizes, 1,3, and 5mm, were investigated, and it was found that the stress concentration at 1mm obtained with 1 mm mesh size could give a fairly well approximation to the global stress concentration at that point. Thus the FEM analysis with 1mm mesh might be taken as a practical approach to calculating $K_{t,global}$ of fillet weld.

3. Examination of the proposed approach

Test results of several types of cruciform joints with comparable dimensions to the reference detail are summarized in Fig. 3, with the mean regression line and the confidence limits at two standard deviations from the mean. Some fatigue test data of in-plane and out-of-plane gusset specimens are shown in Fig. 4(a) and 5(a), respectively. Influence of global stress is demonstrated apparently, i.e., global stress concentration increases with gusset length, hence, fatigue life decreases. These data are also plotted in global stress, Fig. 4(b) and 5(b), with $K_{t,global}$ taken as the value at 1mm from toe calculated with 1mm mesh. Nearly all the data are distributed between the confidence limits of the reference detail. The re-summarized data only reveal the local stress influence as those of reference detail do. New test specimens with combined attachments have also been designed to examine the applicability of the approach to complicated details, and fatigue tests on these specimens are in progress. If all the test results summarized with global stress show a good agreement with the test results of the reference detail, it can be concluded that the proposed approach is a practical one for fatigue life evaluation of fillet weld.

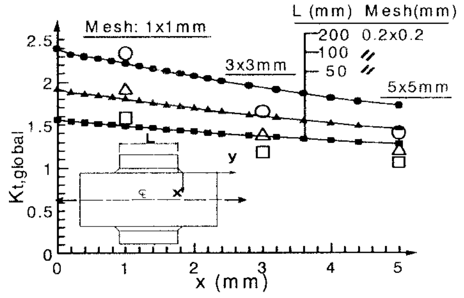

Fig.2 Approximation of $K_{t,global}$

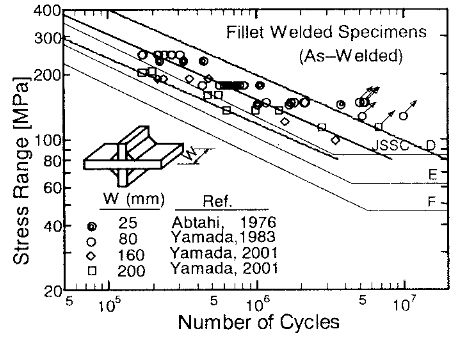

Fig.3 Test Data of Reference Detail

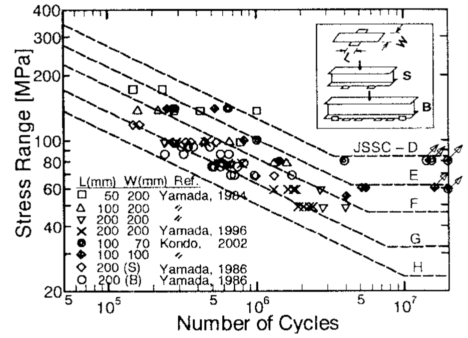

Fig.4 (a) Test Data of In-plane Gusset

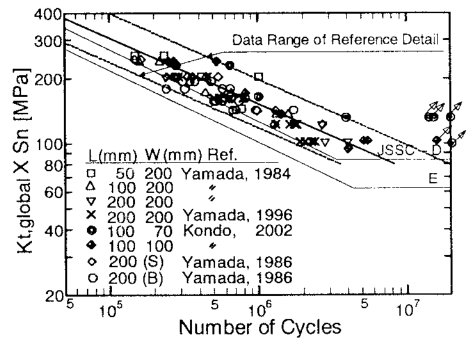

Fig.4 (b) Data in Terms of Global Stress

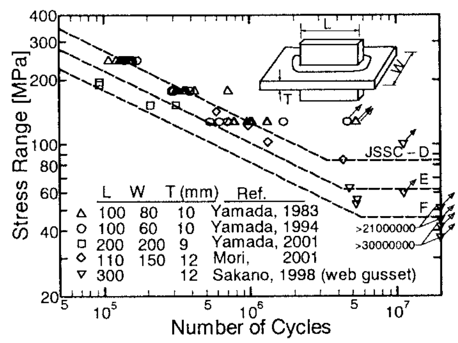

Fig.5 (a) Test Data of out-of-plane Gusset

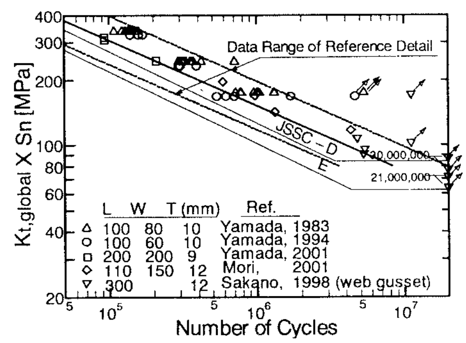

Fig.5 (b) Data in Terms of Global Stress